CSE 167: Introduction to Computer Graphics Lecture #18: Volume Rendering

Jürgen P. Schulze, Ph.D.
University of California, San Diego
Fall Quarter 2013

Announcements

- Cross-check all scores on Ted
- Two more blog deadlines: Sunday and Wednesday
- Final Project Presentations in CSE 1202, Thursday 3-6pm
  - Bring computer with VGA adapter
    - contact instructor if this is not an option for you
- CAPE reminder

Lecture Overview

- Volume Rendering
  - Overview
  - Transfer Functions
  - Rendering

What is Volume Rendering?

- *Volume Rendering* is a set of techniques used to display a 2D projection of a volume data set.
- User specifies viewpoint, rendering algorithm and transfer function
  - Transfer function defines mapping of color and opacity to voxels
- Wide spectrum of application domains

Weather

- Clouds
  - http://www.youtube.com/watch?v=7obZdsEoGGA

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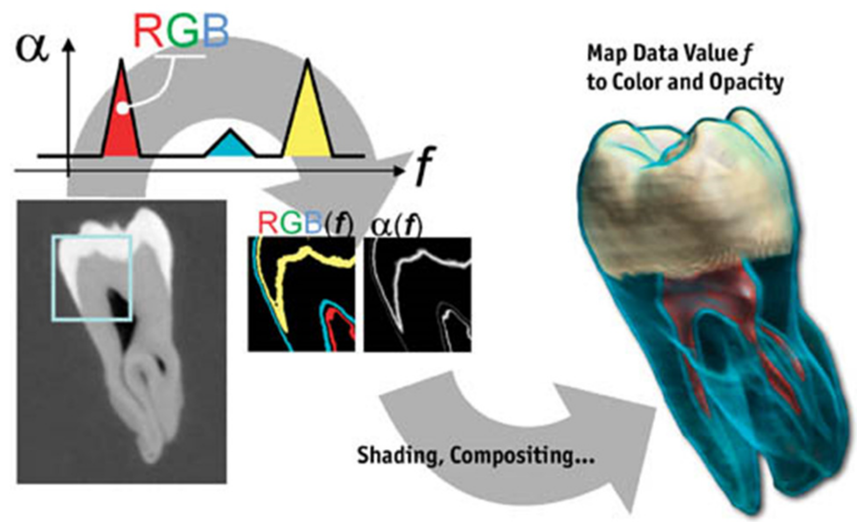
Transfer Functions

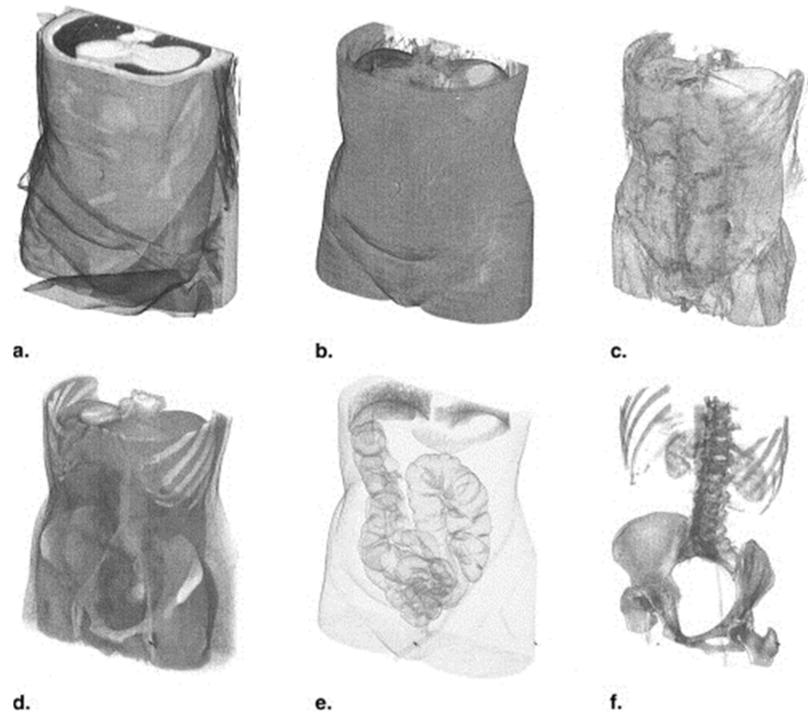
- Most volume data sets consist of a single data value per voxel, for instance the measured material density.
- This data value can be interpreted as:
  - Luminance and rendered as a gray value on a scale from black to white
  - An index into a color look-up table
- Another look-up table maps opacity to data values.



From GPU Gems

Opacity Transfer Function

- Modifying the mapping of data value to opacity exposes different parts of the volume.



From Shin et al. 2004: Images a-f show decreasing opacity.

Volume Filtering

- Applying a filter to the volume data set can improve image quality
- Filtering operation defined by filter kernel
- Filter kernels on right:
  - (a) blur filter
  - (b) sharpen filter
  - (c) edge filter
- In 3D, filter kernels typically use a 6-, 18- or 26-voxel neighborhood

1	1	1
1	1	1
1	1	1

(a)

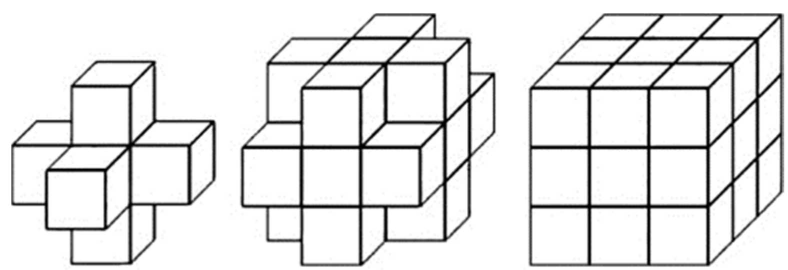
0	-1	0
-1	10	-1
0	-1	0

(b)

0	1	0
1	-4	1
0	1	0

(c)

(d) (e) (f)



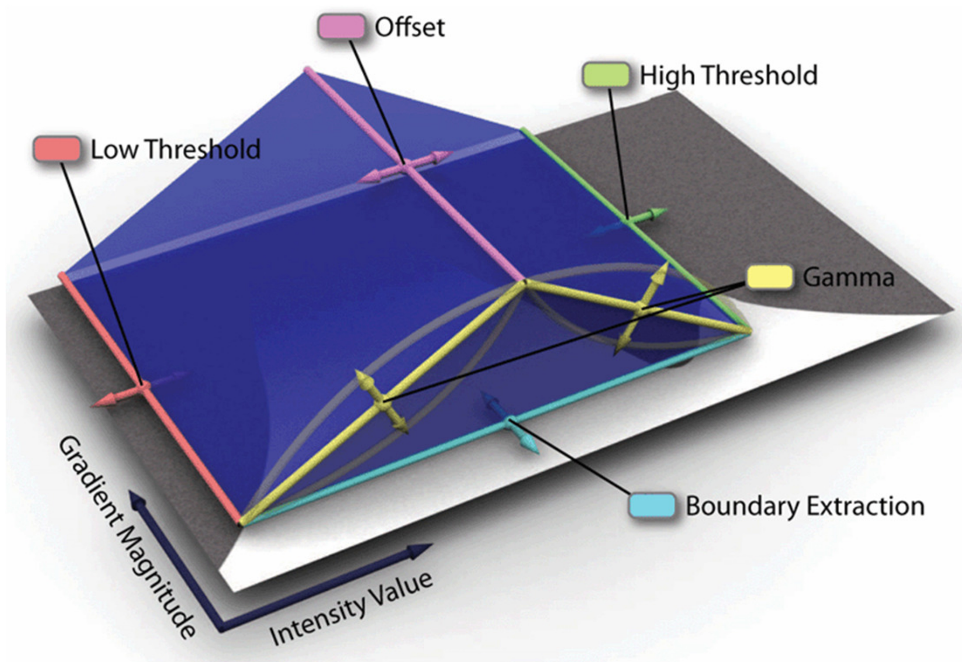
6-Neighborhood 18-Neighborhood 26-Neighborhood

Derived Voxel Data

- Applying a filter on the volume data set generates a new, derived volume data set.
- Derived volume data can be stored with original volume in a multi-channel volume data set.
- Example:
  - Channel 1: original density data
  - Channel 2: gradient magnitude

2D Transfer Functions

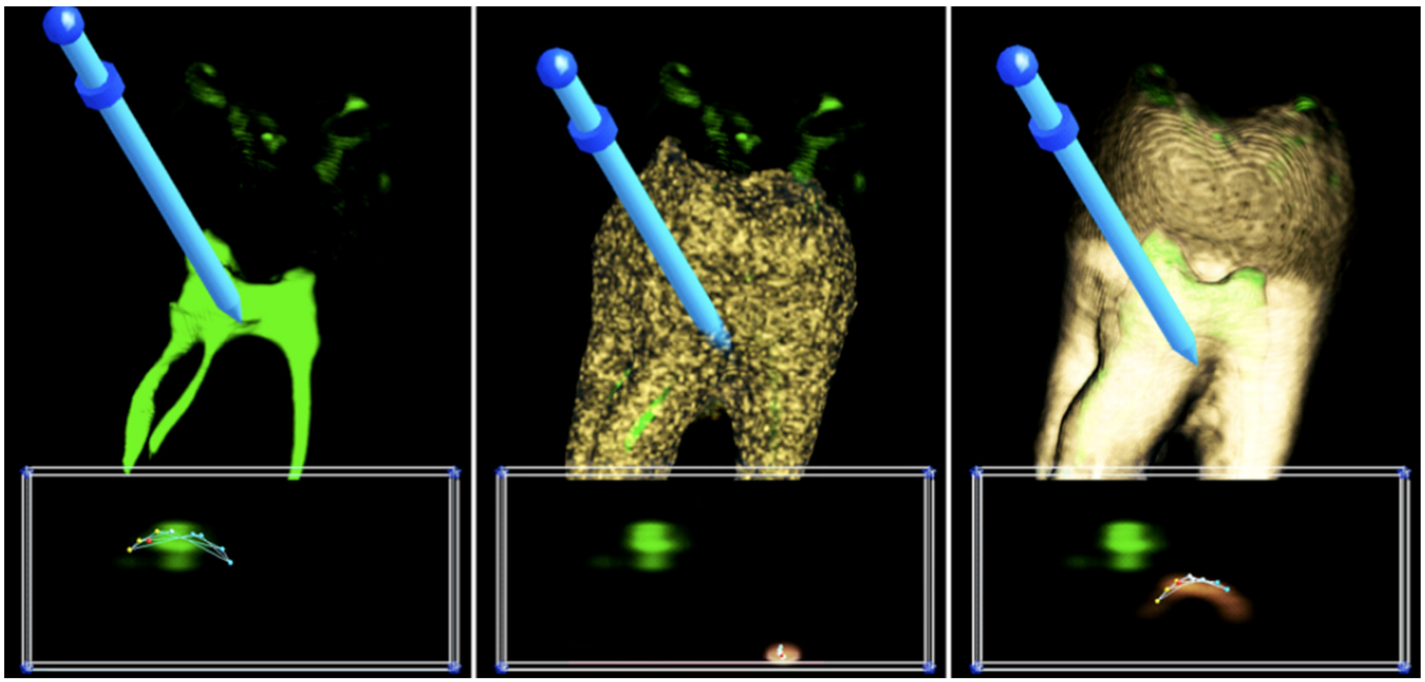
- A 2D transfer function can map RGBA values separately to every combination of density data and gradient magnitude



2D Transfer function and its parameters (Wan et al. 2009)

2D Transfer Functions

- Example: Rectangular 2D transfer function editor



Images by Gordon Kindleman and Joe Kniss

Lecture Overview

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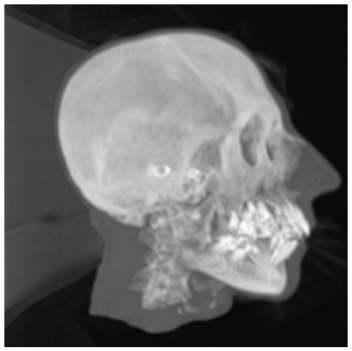
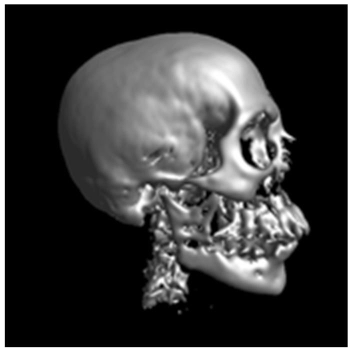
Volume Rendering Techniques

- Iso-surface
- Cross-sections
- Direct volume rendering (DVR)
  - Slicing with 2D textures
  - Translucent textures with image plane-aligned 3D textures
  - MIP
- Spatial constraints
  - Region of interest (cubic, spherical, slab)
  - Clipping plane

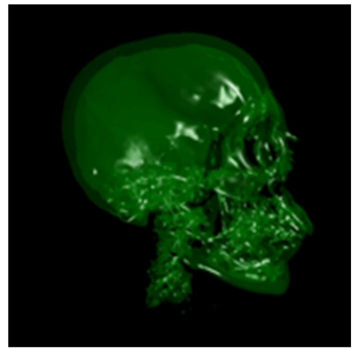
Volume Rendering Techniques



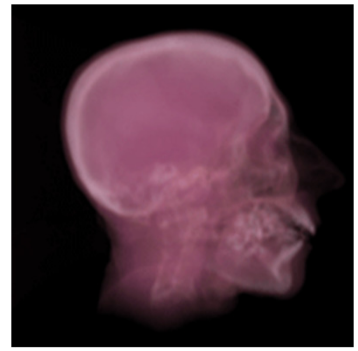
Maximum Intensity Projection



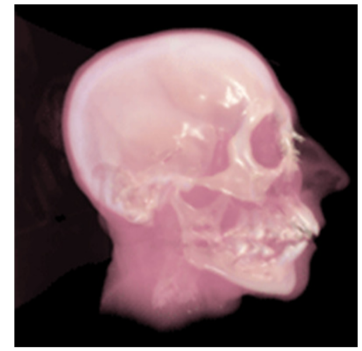
Iso-Surface



Transparent Iso-Surfaces



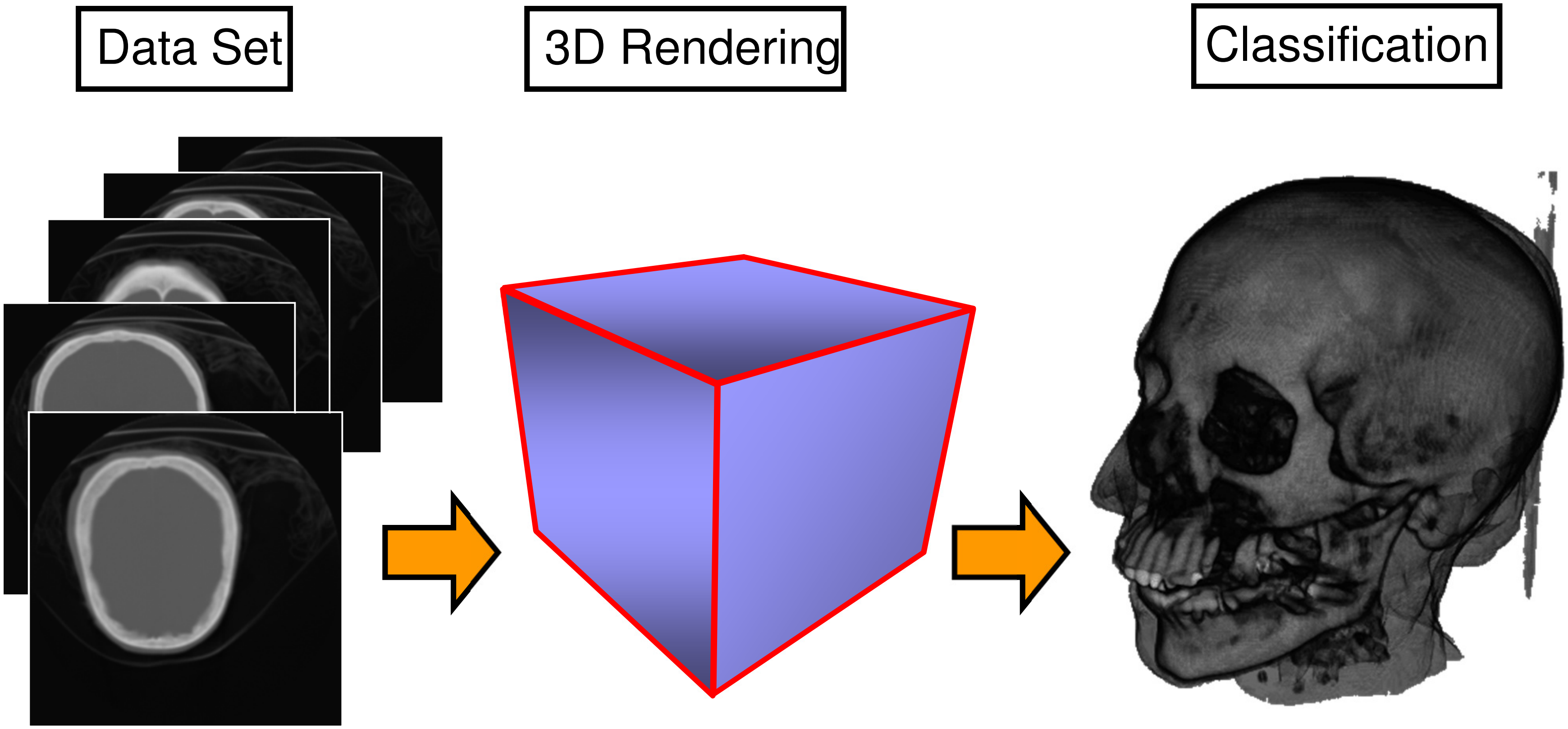
Raycasting (DVR)



Raycasting and Iso-Surface

Images from: A Simple and Flexible Volume Rendering Framework for Graphics-Hardware-based Raycasting, Stegmaier et al. 2005

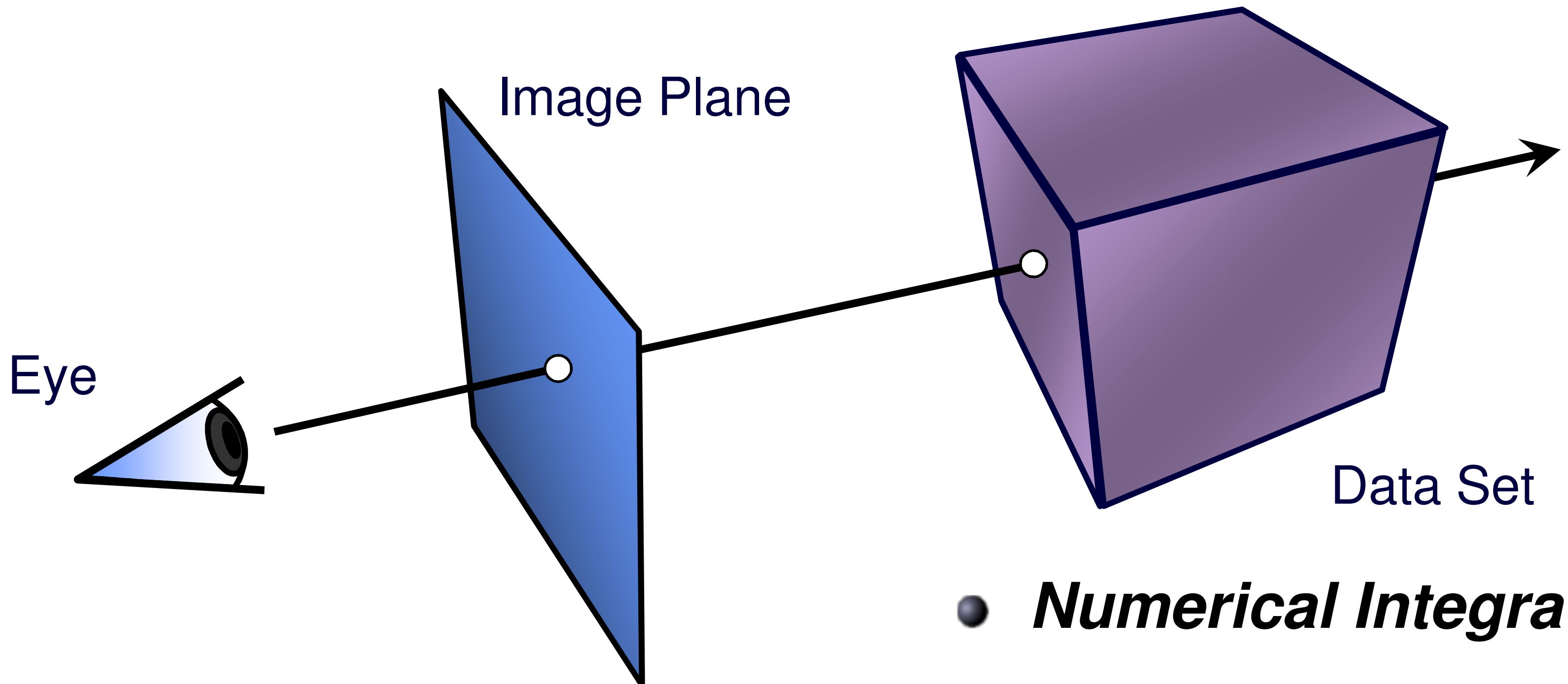
Volume Rendering Outline



Rendering done in real-time on
commodity graphics hardware

Ray Casting

- Software Solution

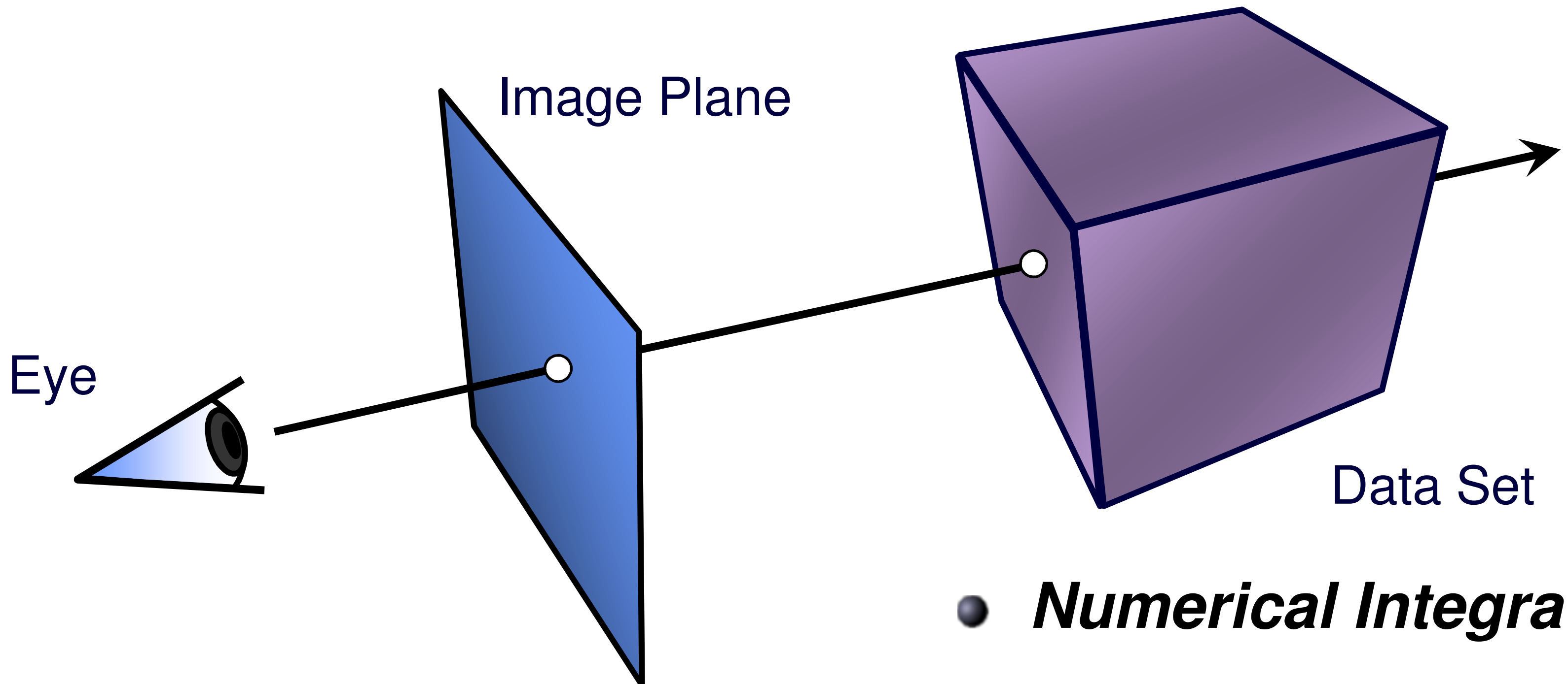


- ***Numerical Integration***
- ***Resampling***

➡ ***High Computational Load***

Ray Casting

- Software Solution

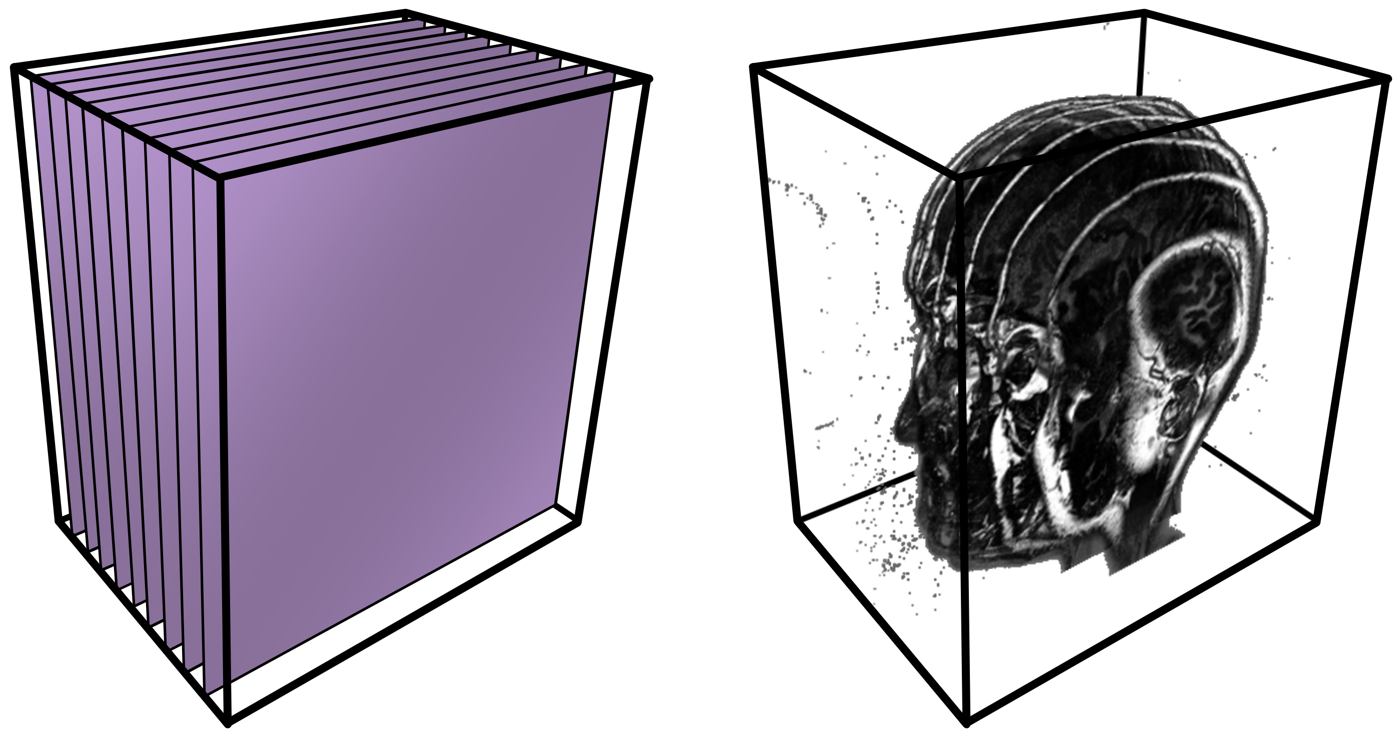


- ***Numerical Integration***
- ***Resampling***

➡ ***High Computational Load***

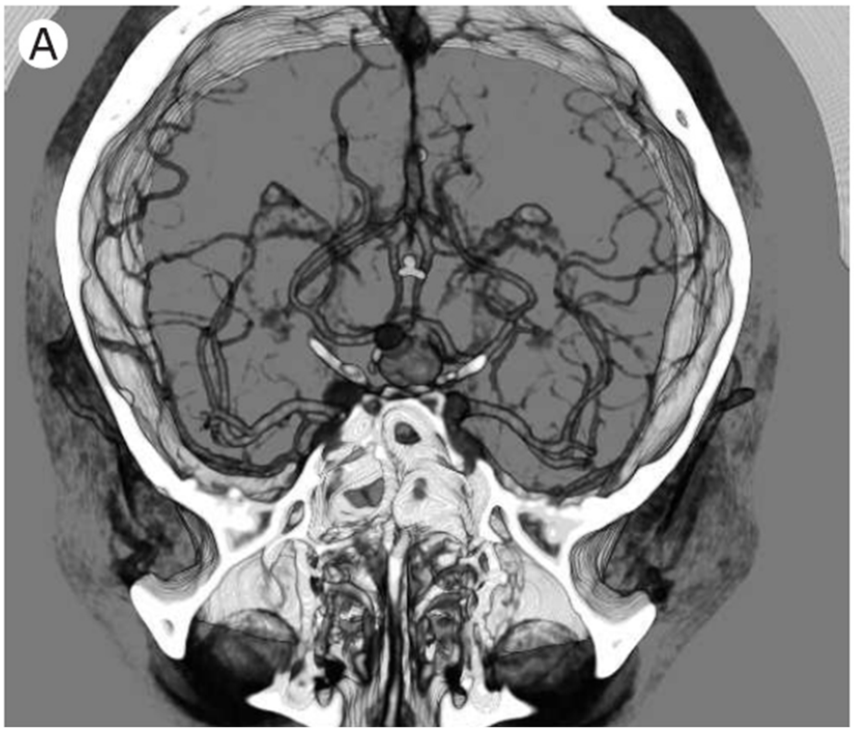
Plane Compositing

- Proxy geometry (Polygonal Slices)

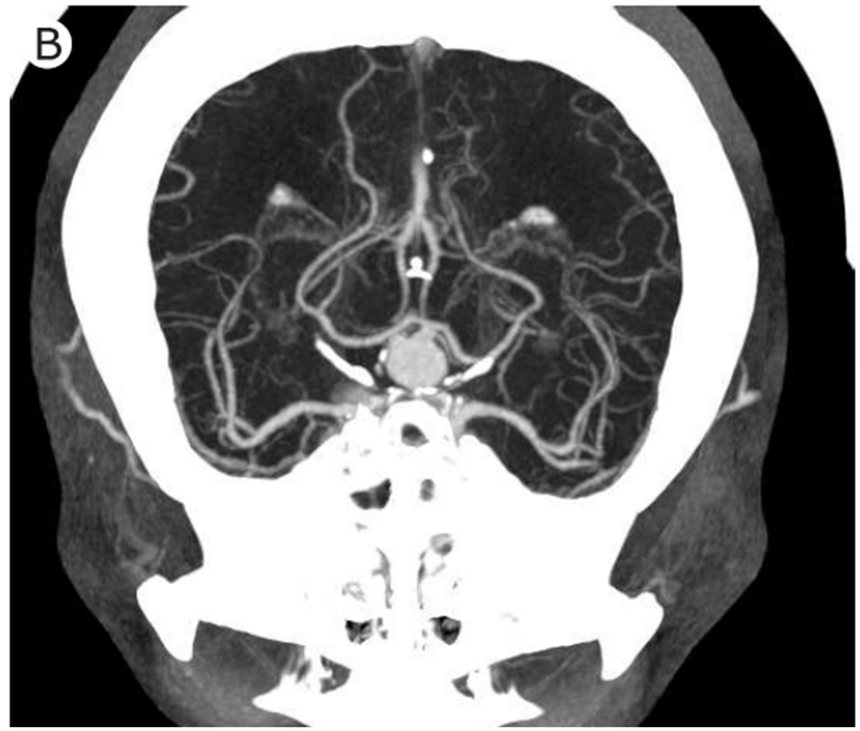


Compositing

- ***Maximum Intensity Projection***
  No emission/absorption
  Simply compute maximum value along a ray



Emission/Absorption

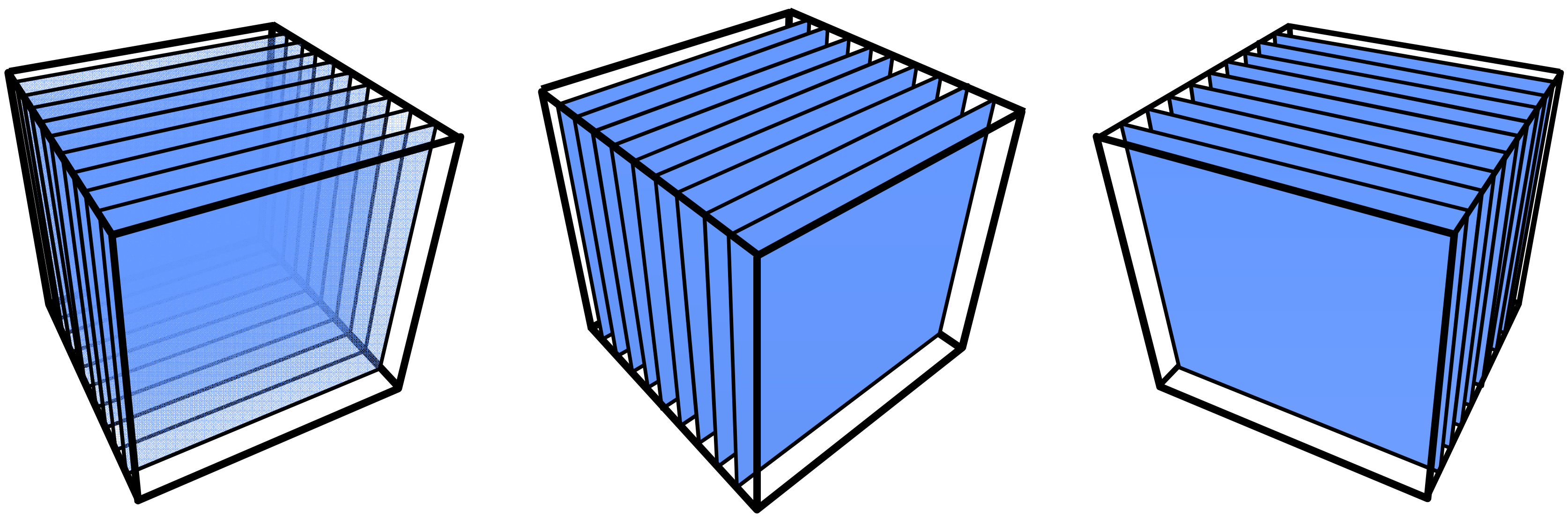


Maximum Intensity Projection

2D Textures

- Draw the volume as a stack of 2D textures
  Bilinear Interpolation in Hardware

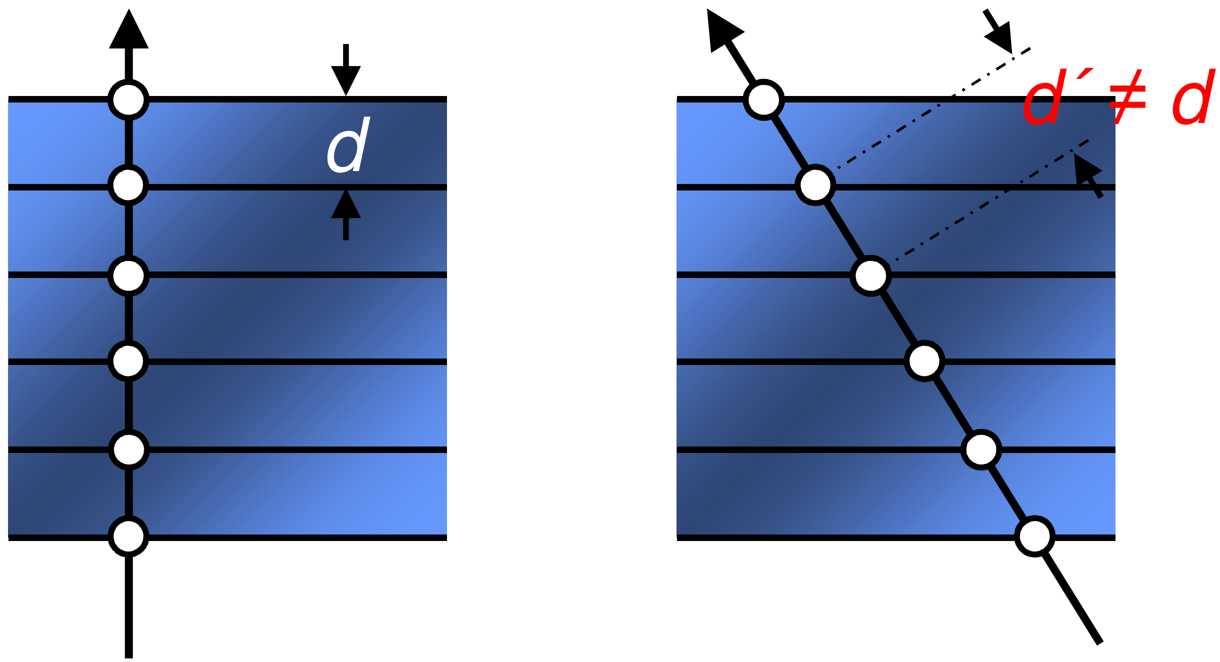
➡ Decompostition into axis-aligned slices



- 3 copies of the data set in memory

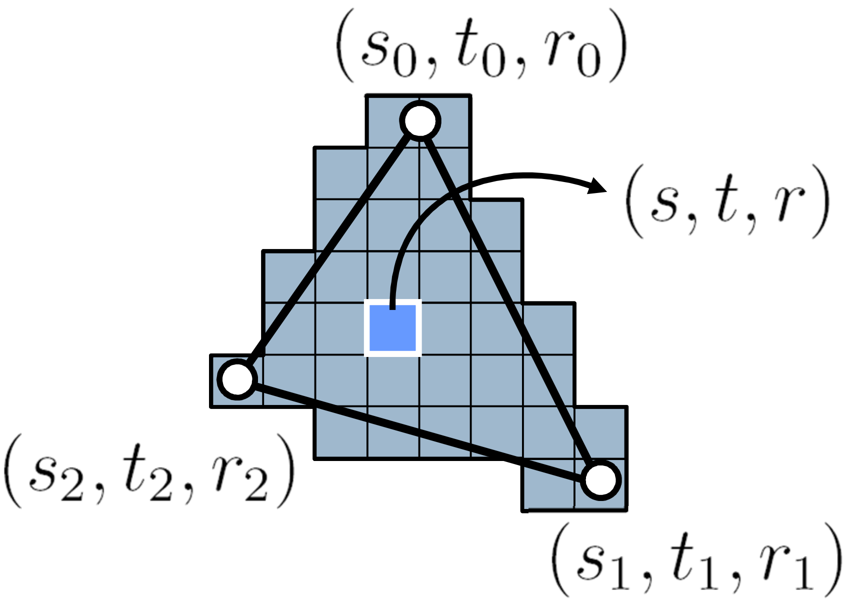
2D Textures: Drawbacks

- Sampling rate is inconsistent

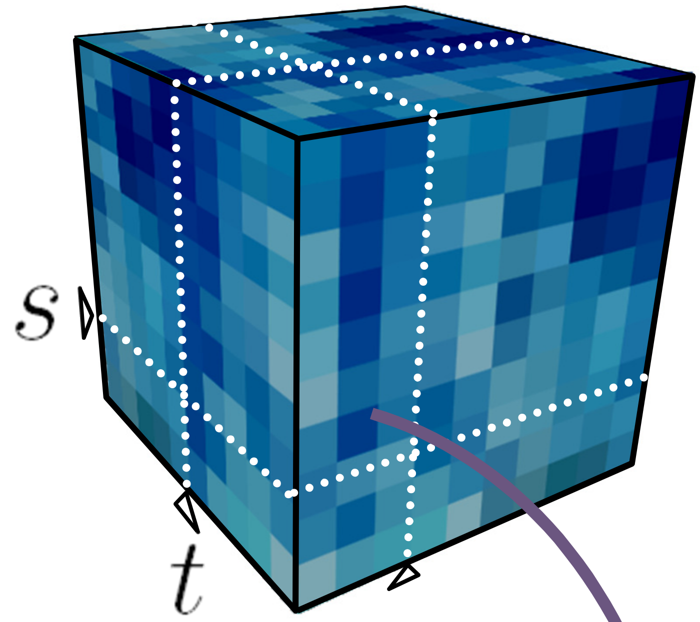


- Emission/absorption slightly incorrect
- ***Super-sampling on-the-fly impossible***

3D Textures



For each fragment:
interpolate the
texture coordinates
(barycentric)



Texture-Lookup:
interpolate the
texture color
(trilinear)

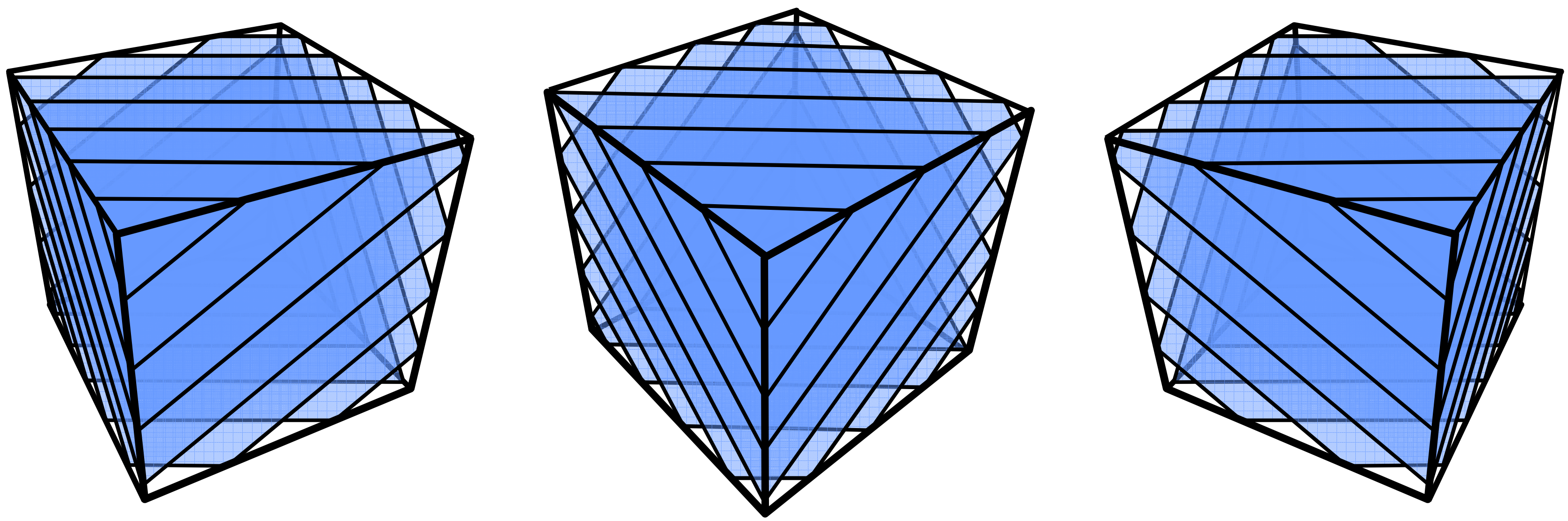
R G B A

3D Textures

3D Texture: Volumetric Texture Object

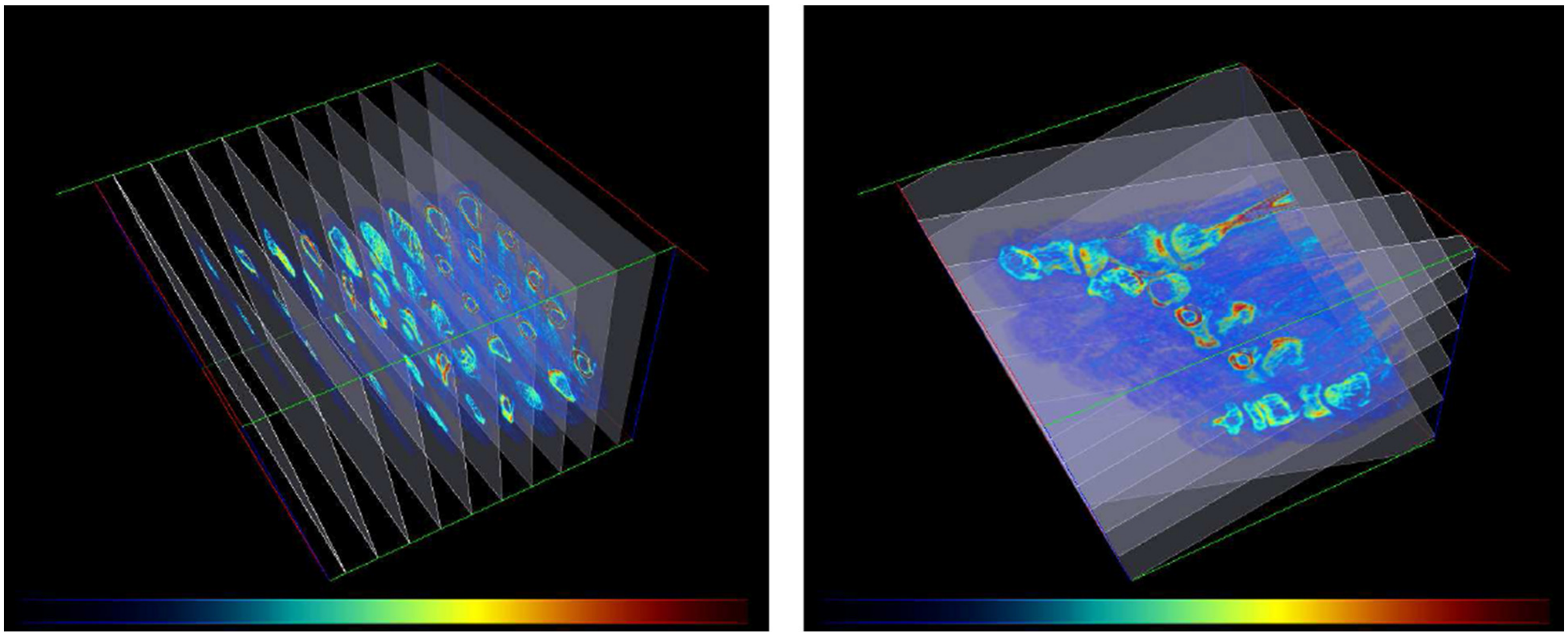
- Trilinear Interpolation in Hardware

➨ Slices parallel to the image plane



- One large texture block in memory

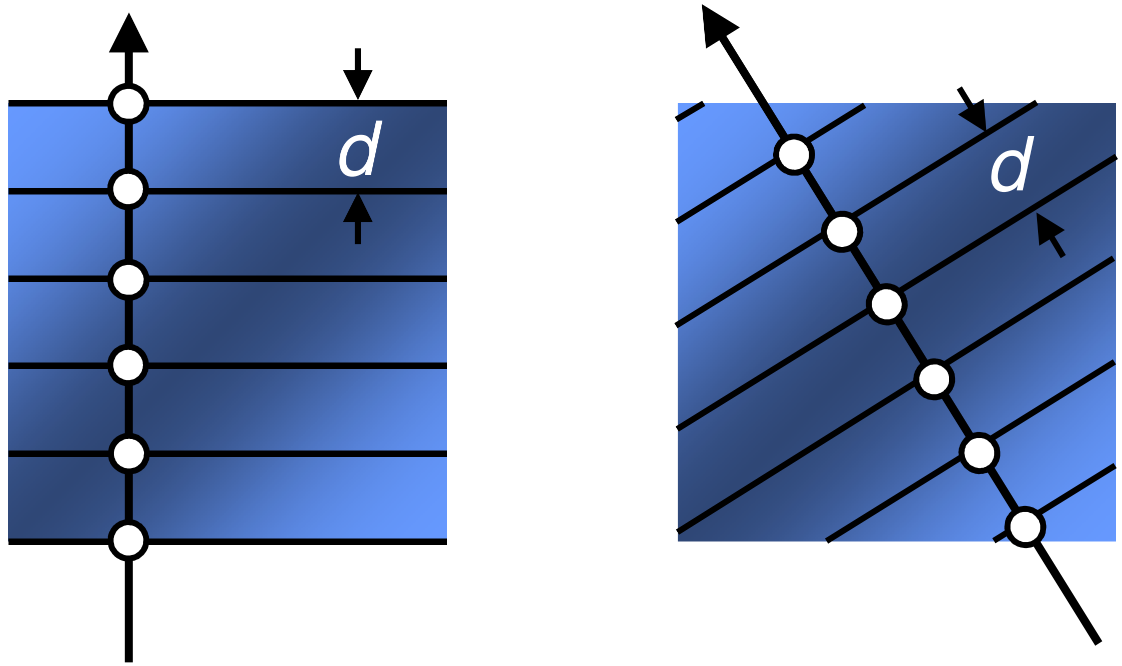
Comparison of 2D with 3D Texturing



Left: 2D textures, right: 3D textures
[Lewiner2006]

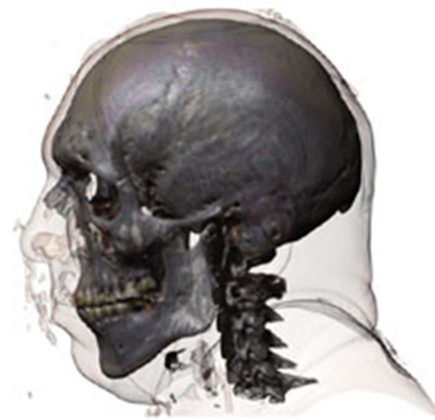
Resampling via 3D Textures

- ***Sampling rate is constant***



- Supersampling by increasing the number of slices

Shadows

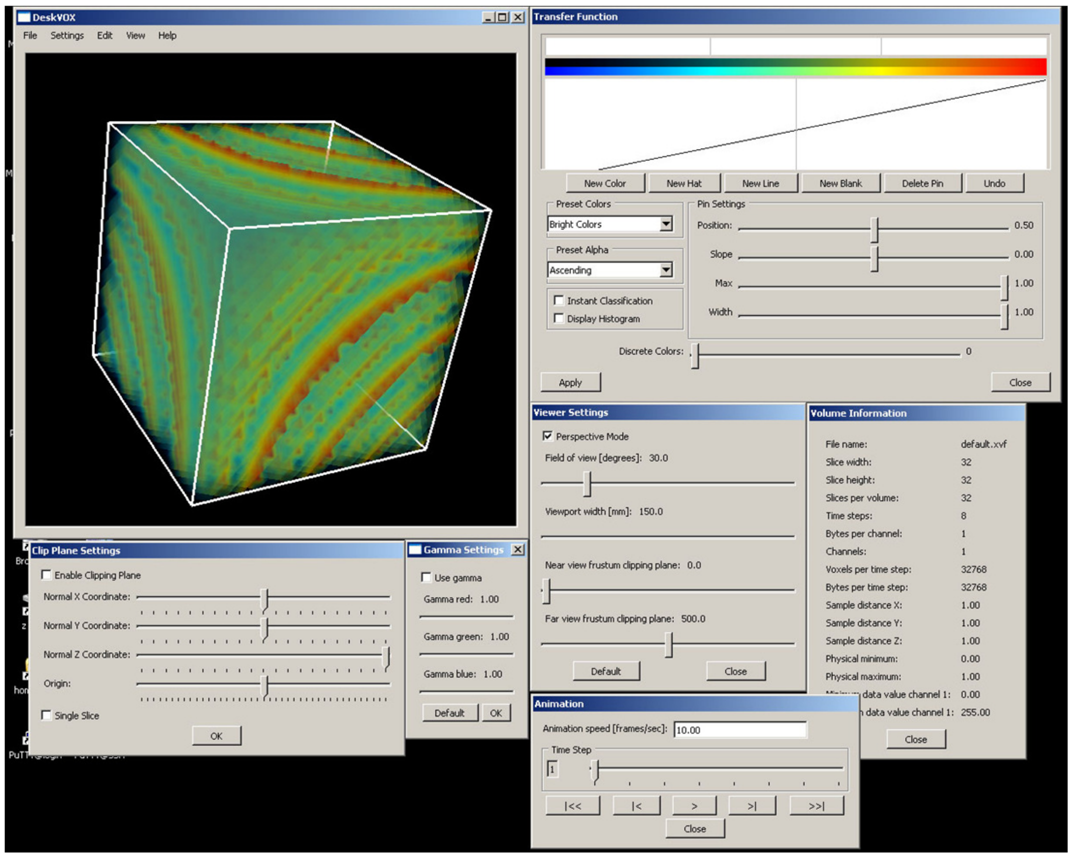
Volume rendering with shadows
(from GPU Gems)

Implementation: Loading a 3D Texture

- // init the 3D texture
- glEnable(GL_TEXTURE_3D_EXT);
- glGenTextures(1, &tex_glid);
- glBindTexture(GL_TEXTURE_3D_EXT, tex_glid);
- // texture environment setup
- glTexParameteri(GL_TEXTURE_3D_EXT, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
- glTexParameteri(GL_TEXTURE_3D_EXT, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
- glTexParameteri(GL_TEXTURE_3D_EXT, GL_TEXTURE_WRAP_R, GL_CLAMP_TO_EDGE);
- glTexParameteri(GL_TEXTURE_3D_EXT, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_EDGE);
- glTexParameteri(GL_TEXTURE_3D_EXT, GL_TEXTURE_WRAP_T, GL_CLAMP_TO_EDGE);
- // load the texture image
- glTexImage3DEXT(GL_TEXTURE_3D_EXT, // target
- 0, // level
- GL_RGBA, // color storage
- (int) tex_ni(), // width
- (int) tex_nj(), // height
- (int) tex_nk(), // depth
- 0, // border
- GL_COLOR_INDEX, // format
- GL_FLOAT, // type
- _texture); // allocated texture buffer
- glPixelTransferi(GL_MAP_COLOR, GL_FALSE);

Demo: DeskVox

- DeskVox was created at IVL/Calit2
  - http://ivl.calit2.net/wiki/index.php/VOX_and_Virvo



Videos

- Human head, rendered with 3D texture:
  - http://www.youtube.com/watch?v=94_Zs_6AmQw
- GigaVoxels:
  - http://www.youtube.com/watch?v=HScYuRhgEJw

References

- Volume rendering tutorial with source code
  - http://graphicsrunner.blogspot.com/2009_01_01_archive.html
- Simian volume rendering software
  - http://www.cs.utah.edu/~jmk/simian/

Lecture Overview

- Deferred Rendering Techniques
  - Deferred Shading
  - Screen Space Ambient Occlusion
  - Bloom
  - Glow

Deferred Rendering

- Opposite to Forward Rendering, which is the way we have rendered with OpenGL so far
- Deferred rendering describes post-processing algorithms
  - Requires two-pass rendering
  - First pass:
    - Scene is rendered as usual by projecting 3D primitives to 2D screen space.
    - Additionally, an off-screen buffer (G-buffer) is populated with additional information about the geometry elements at every pixel
      - Examples: normals, diffuse shading color, position, texture coordinates
  - Second pass:
    - An algorithm, typically implemented as a shader, processes the G-buffer to generate the final image in the back buffer

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Deferred Shading

- Postpones shading calculations for a fragment until its visibility is completely determined
  - Only fragments that really contribute to the image are shaded
- Algorithm:
  - Fill a set of buffers with common data, such as diffuse texture, normals, material properties
  - For the lighting just render the light extents and fetch data from these buffers for the lighting computation
- Advantages:
  - Decouples lighting from geometry
  - Several lights can be applied with a single draw call: more than 1000 light sources can be rendered at 60 fps
- Disadvantages:
  - Consumes more memory, bandwidth and shader instructions than traditional rendering

Particle system with glowing particles. Source: Humus 3D

Reference

- Deferred Shading Tutorial:
  - http://bat710.univ-lyon1.fr/~jciehl/Public/educ/GAMA/2007/Deferred_Shading_Tutorial_SBGAMES2005.pdf

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Screen Space Ambient Occlusion

- Screen Space Ambient Occlusion is abbreviated as SSAO
- "Screen Space" refers to this being a deferred rendering approach
- Rendering technique for approximating ambient occlusion in real time
- Developed by Vladimir Kajalin while working at Crytek
- First use in 2007 PC game Crysis

SSAO component

Ambient Occlusion

- Attempts to approximate global illumination
  - Very crude approximation
- Unlike local methods like Phong shading, ambient occlusion is a global method
  - Illumination at each point is a function of other geometry in the scene
- Appearance achieved by ambient occlusion is similar to the way an object appears on an overcast day
  - Example: arm pit is hit by a lot less light than top of head
- In the industry, ambient occlusion is often referred to as "sky light"

SSAO Demo

- Screen Space Ambient Occlusion (SSAO) in Crysis
  - http://www.youtube.com/watch?v=ifdAILHTcZk

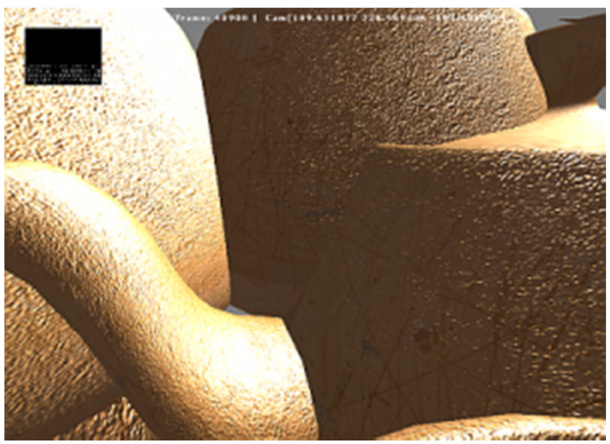
Basic SSAO Algorithm

- First pass:
  - Render scene normally and write z values to g-buffer's alpha channel
- Second pass:
  - Pixel shader samples depth values around the processed fragment and computes amount of occlusion, stores result in red channel
  - Occlusion depends on depth difference between sampled fragment and currently processed fragment

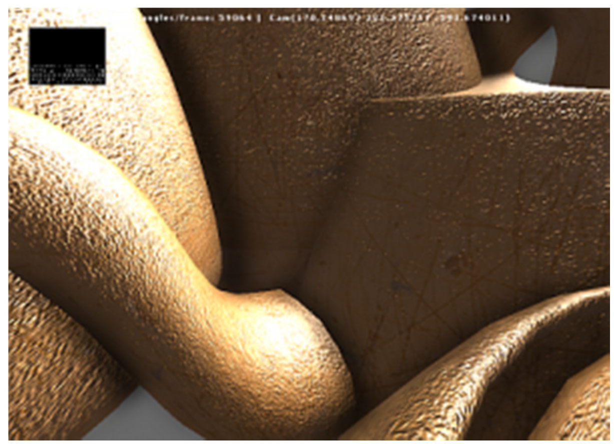
Ambient occlusion values in red color channel
Source: www.gamerendering.com

SSAO With Normals

- First pass:
  - Render scene normally and copy z values to g-buffer's alpha channel and scene normals to g-buffer's RGB channels
- Second pass:
  - Use normals and z-values to compute occlusion between current pixel and several samples around that pixel



No SSAO



With SSAO

SSAO Discussion

- Advantages:
  - Deferred rendering algorithm: independent of scene complexity
  - No pre-processing, no memory allocation in RAM
  - Works with dynamic scenes
  - Works in the same way for every pixel
  - No CPU usage: executed completely on GPU
- Disadvantages:
  - Local and view-dependent (dependent on adjacent texel depths)
  - Hard to correctly smooth/blur out noise without interfering with depth discontinuities, such as object edges, which should not be smoothed out

References

- Nvidia's documentation:
  - http://developer.download.nvidia.com/SDK/10.5/direct3d/Source/ScreenSpaceAO/doc/ScreenSpaceAO.pdf
- SSAO shader code from Crysis:
  - http://69.163.227.177/forum.php?mod=viewthread&tid=772
- Another implementation:
  - http://www.gamerendering.com/2009/01/14/ssao/

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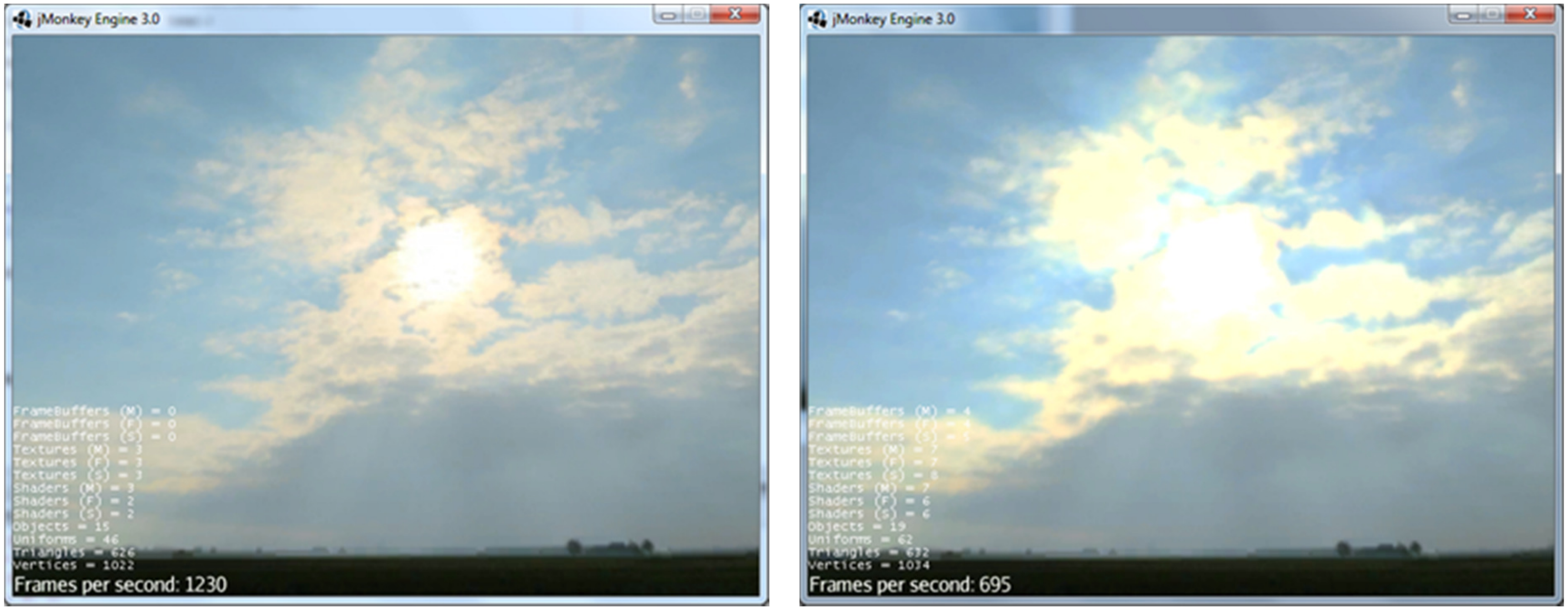
Bloom Effect

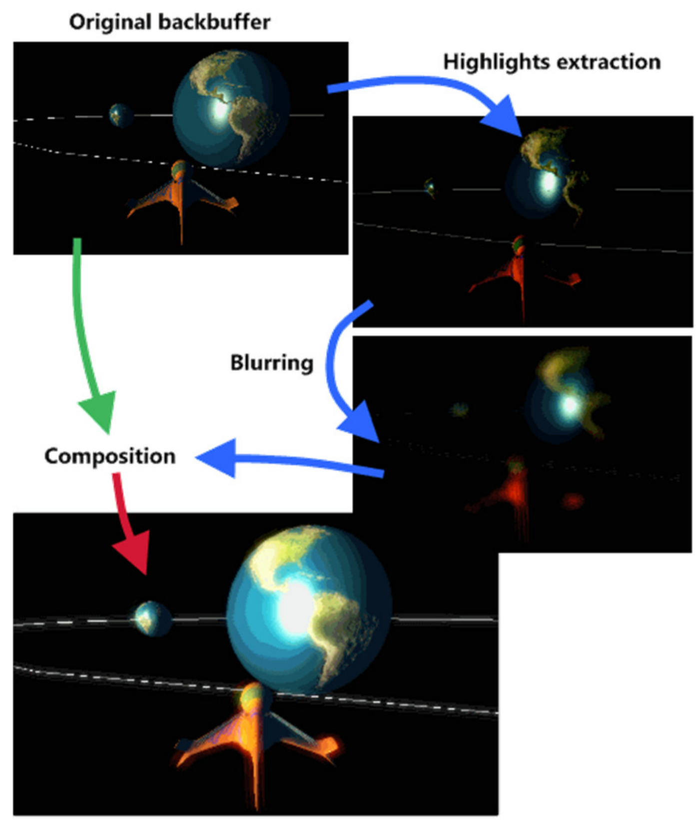


Left: no bloom, right: bloom.
Source: http://jmonkeyengine.org

- Bloom gives a scene a look of bright lighting and overexposure

Bloom Shader

- Post-processing filter: applied after scene is rendered normally
- Step 1: Extract all highlights of the rendered scene, superimpose them and make them more intense
  - Operates on back buffer
  - Often done with off-screen buffer smaller than frame buffer
  - Highlights found by thresholding luminance
- Step 2: Blur off-screen buffer, e.g., with Gaussian blurring
- Step 3: Composite off-screen buffer with back buffer



Bloom shader render steps.
Source: http://www.klopfenstein.net

References

- Bloom Shader
  - http://www.klopfenstein.net/lorenz.aspx/gamecomponents-the-bloom-post-processing-filter
- GLSL Shader for Gaussian Blur
  - http://www.ozone3d.net/tutorials/image_filtering_p2.php

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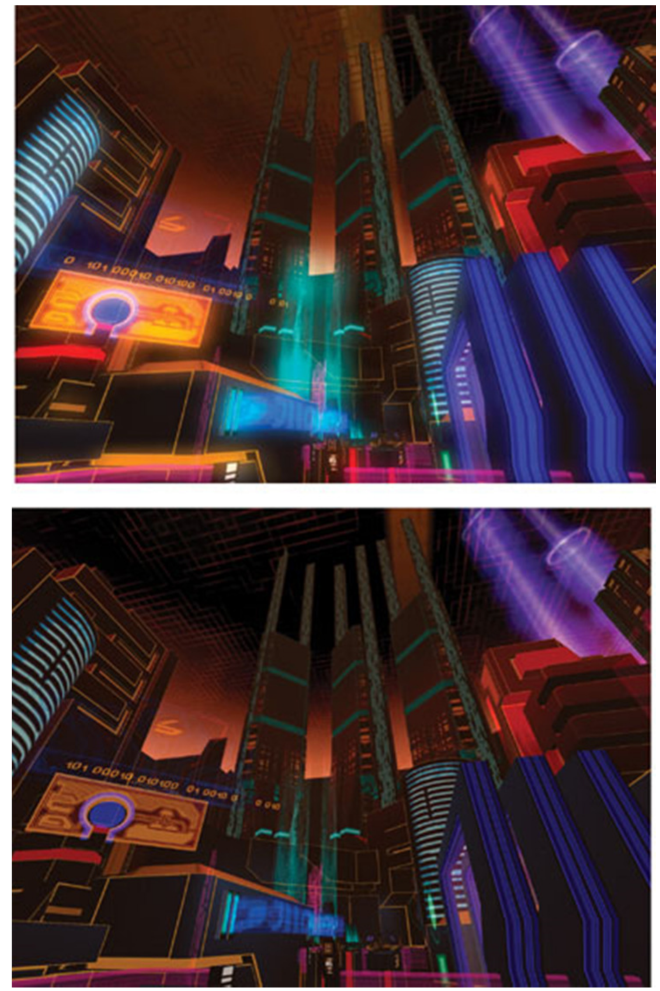
Glow Effects

- Glows and halos of light appear everywhere in the world
- They provide powerful visual cues about brightness and atmosphere
- In computer graphics, the intensity of light reaching the eye is limited, so the only way to distinguish intense sources of light is by their surrounding glow and halos
- In everyday life, glows and halos are caused by light scattering in the atmosphere or within our eyes



A cityscape with and without glow. Source: GPU Gems

Glow vs. Bloom

- Bloom filter looks for highlights automatically, based on a threshold value
- If you want to have more control over what glows and does not glow, a glow filter is needed
- Glow filter adds an additional step to Bloom filter: instead of thresholding, only the glowing objects are rendered
- Render passes:
  - Render entire scene back buffer
  - Render only glowing objects to a smaller off-screen glow buffer
  - Apply a bloom pixel shader to glow buffer
  - Compose back buffer and glow buffer together

References

- GPU Gems Chapter on Glow
  - http://http.developer.nvidia.com/GPUGems/gpugems_ch21.html
- Bloom and Glow
  - http://jmonkeyengine.org/wiki/doku.php/jme3:advanced:bloom_and_glow

The Future of Computer Graphics

- ACM SIGGRAPH Asia, 19.11.-22.11.2014 in Hong Kong (3:18)
  - http://www.youtube.com/watch?v=FUGVF_eMeo4
- ACM SIGGRAPH, August 10-14, 2014, Vancouver
  - Student volunteer application deadline: Feb 9, 2014

- Cryengine 4 Trailer
  - http://www.youtube.com/watch?v=aseq4T81P7g

Good luck with your final projects!